TU4C-3
Waveguide Multimode Directional Coupler for Harvesting Harmonic Power from the Output of Traveling-Wave Tube Amplifiers

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Introduction – Motivation

• Growing user community
  – Congestion in the traditional Ku, K, and Ka frequency bands designated for space-to-ground data communications

• Next available bands above Ka-band are the Q-band (37-42 GHz) and E-band (71-76 GHz)
Benefits of Migrating to Higher Frequencies

- Allocated bandwidth at Q-band & E-band is in excess of 4 GHz, which can enhance throughput by 10X or higher
  - Competitive with terrestrial fiber optic & wireless service in terms of cost per transmitted bit
- Narrower beam width & smaller spot size
- Greater frequency reuse & spectral efficiency
Challenges

- Lack of rigorous studies to understand atmospheric effects on radio wave propagation at Q-band & E-band
  - These studies are essential for the design of a robust system for deployment in space
Challenges (continued)

- A wide band beacon transmitter has to be deployed on a satellite
  - Ground receivers have to be dispersed over climate zones of interest
  - Statistical data on rain attenuation, fading, change in refractive index, scintillation, de-polarization effects, etc., have to be acquired for a period of 3 to 5 years
High Power Amplifier Harmonics

\[ P_{\text{in}} (f_0) \rightarrow \text{High Power Amplifier} \rightarrow P_{\text{out}} (f_0, 2f_0, 3f_0, \ldots) \]

**Example:** Measured values range from 20 to 23 dBm (100 to 200 mW) for the 40 W K-band TWTA

TWTAs on board satellites for data transmission operate with constant envelope type waveform (for e.g. QPSK) and at saturation for peak efficiency.
Waveguide Multimode Directional Coupler (MDC)

Ku-band WR–62 primary waveguide inside 15.799×7.899 mm

14.1 GHz

Port 2

28.2 GHz

Port 4

WR–28 secondary waveguide inside 7.112×3.556 mm

14.1 and 28.2 GHz

Port 3

Port 1

Ka-band WR–28 waveguide centered on the WR–62 waveguide vertical wall
Fabricated Ku-Band/Ka-Band Waveguide MDC
Test Circuit for Measurement of Power at Fundamental ($f_0$) & Second Harmonic ($2f_0$)
Experimental Setup - Ku-Band/Ka-Band MDC Tests
MDC at Output Port of Ku-Band TWTA
Measured TWT Fundamental ($f_0$) Saturated Output Power
Measured Second Harmonic ($2f_0$) Power at Port 4 of MDC
Measured $f_0$ Power at the MDC Port 4 & Measured Insertion Loss Between Port 1 & Port 2
Fabricated Ka-Band/E-Band Waveguide MDC
Test Circuit for Measurement of Power at Fundamental ($f_0$) & Second Harmonic ($2f_0$)
Experimental Setup - Ku-Band/Ka-Band MDC Tests
Measured TWT Fundamental ($f_0$) Saturated Output Power

![Graph showing the relationship between TWT fundamental output power and input power with respect to fundamental frequency. The graph plots dBm on the y-axis and GHz on the x-axis, with two lines representing TWT output power and TWT input power.](image-url)
Measured Second Harmonic (2f₀) Power at Port 4 of MDC With & Without the LNA
Conclusions

• Design, fabrication and test results are presented for a Ku-Band/Ka-Band & Ka-Band/E-Band MDCs

• The MDC can be connected directly to the output port of a TWTA with negligible loss of fundamental power – an advantage over harmonic filters and diplexers

• Test results demonstrate sufficient power in the 2nd harmonic for potential space borne beacon source for atmospheric studies